UCRL-PROP-137401

Informal Proposal for a New Task in the Enabling Technology Program: Implications of Fast Ignition for Inertial Fusion Energy Power Plants

J.F. Latkowski, B.G. Logan, W.R. Meier, L.J. Perkins, P.F. Peterson, R.B. Stephens, M. Tabak

February 1, 2000

Work performed under the auspices of the U. S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Informal Proposal for a New Task in the Enabling Technology Program:

Implications of Fast Ignition for Inertial Fusion Energy Power Plants*

J.F. Latkowski[a], B.G. Logan[a], W.R. Meier[a], L.J. Perkins[a],
P.F. Peterson[b], R. B. Stephens[c], and M. Tabak[a]

[a] Lawrence Livermore National Laboratory, P. O. Box 808, L-446, Livermore, CA 94550
[b] University of California at Berkeley, 4118 Etcheverry Hall, Berkeley, CA 94720
[c] General Atomics, P. O. Box 85608, San Diego, CA 92186

Summary

The possibility of fast ignition offers a fundamental step-change in the pursuit of inertial fusion energy (IFE) [1]. The implications of fast ignition range from reduced total driver energies, and thus, reduced driver costs and cost of electricity (COE) to the ability to use advanced, tritium-lean targets and take advantage of their potential for reduced radiation damage rates, elimination of breeding blankets, and exceptional safety and environmental characteristics [2-4]. An additional benefit of fast ignition is a relaxation of target fabrication requirements, which is expected to translate into a reduced size and cost of the target fabrication facility. Fast ignition is also expected to open the parameter space for innovation in chamber design (materials and configuration) and power conversion system design.

We propose to explore the parameter space and quantify the power plant advantages of fast ignition for a range of targets from traditional equimolar, deuterium-tritium (D-T) targets to highly tritium-lean targets using a only D-T "sparkplug." It is our belief that fast ignition will offer an alternate pathway to attractive IFE power plants with a reduced development cost. This work will leverage off of current (FY2000) target design activities, which are funded by the Office of Fusion Energy Sciences (OFES).

Concept Description and Benefits

While conventional IFE target designs assume that the same driver will be used for both compression and central hot-spot ignition, fast ignition would use a low-energy, short-pulsed laser to ignite the edge of the fuel after the main driver compressed the fuel to

* Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

high density. This two-step process appears to significantly reduce the total driver energy that is required. A reduction in the driver energy translates into cost savings in both driver development and construction. Alternatively, one could choose to hold the driver energy constant and reap the benefit of higher fusion yields or move to advanced targets that might have significantly lower tritium inventories and many interesting characteristics. The use of fast ignition offers a wide range of possible parameters—a few brief examples of this parameter space follow.

Implementation of fast ignition with traditional D-T capsules would reduce the required driver energy from 3-5 MJ to less than 1 MJ [5]. Even with the added cost of the ignition beam(s), this might provide a capital cost savings of 30-40%. Since the COE is essentially proportional to this cost, it also would fall by a similar percentage [5].

Alternatively, one could hold the total driver energy constant and reach higher fusion yields. The yield per target would increase from 400 MJ to more than 1000 MJ [5]. This increased yield could support a reduction in the repetition rate from ~ 5-10 Hz to only 1-2 Hz. A wider range of available target yields increases chamber design flexibility. For example, at such low repetition rates, chamber clearing might be able to rely upon gravity rather than forced flow schemes with a large pumping power.

Fast ignition could also make the use of advanced fuels viable at reasonable driver energies. Such fuels would operate at high areal (ρr) densities of 10-20 g/cm^2 and have overall tritium fractions as low as 0.5% [3]. The main fuel mass would be deuterium only, but a small sparkplug region would contain 20-50% tritium, which the ignitor beam would strike. Due to the high values of ρr and low tritium inventories, such targets would be self-sufficient from a tritium breeding perspective—*a breeding blanket would not be required*. Freed from the need to keep the blanket tritium breeding ratio (TBR) above unity, one could select materials by other design criteria. Items such as vapor pressure (affects beam propagation), chemical compatibility, power conversion (higher temperature operation and/or direct conversion), pumping power (important for liquid wall chambers), coolant material abundance and cost, and safety and environmental aspects could be emphasized instead in the selection of materials and chamber design.

In addition to the above examples, fast ignition targets may be simpler and more robust than their traditional counterparts. *Figure 1* shows a target concept in which the compression beams come from one side [5]. This would have the added benefit of excluding the plasma blowoff from the ignitor laser path. Since a central spark is not needed, there is no problem with central mixing caused by a rough interior ice surface [5]. This might allow one to hard freeze targets down to 4 K, simplifying storage and injection. Alternate fuels with reduced cryogenic requirements might be possible. For example, $B_2D_3T_3$ melts above liquid nitrogen temperatures [5].

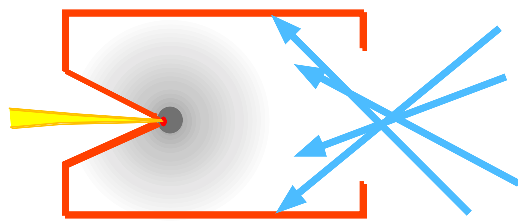

Fig. 1. Fast ignition target concept showing driver (blue) and ignitor (yellow) beams. In this concept, plasma blowoff is excluded from the ignitor laser path and the driver lasers are concentrated at one end of the chamber.

Technical Issues and Proposed Work

The technical issues related to fast ignition physics and target design are numerous. This proposal does not intend to answer those questions but rather to utilize the best current thinking. Fast ignition physics is being studied by groups domestically and internationally. While fast ignition target designs are being developed as part of the IFE Science program funded by OFES for FY2000, some modifications and analyses are needed to specifically support this proposal. We propose to leverage efforts in target design by focusing on the **power plant design issues** and implications of fast ignition. Proposed areas of research are target design, target fabrication and injection, blanket engineering, and power plant design and economics. Each area is summarized below.

Target design: An integrated set of calculations for a fast ignition target design similar to that shown in *figure 1* will be performed with the LASNEX radiation hydrodynamics code. Additional work on tritium-lean, fast ignition targets, such as those presented in references 2 and 3, is needed to verify the required driver energies, fusion yields, and internal tritium production. These designs will be modified to minimize the total driver energy and increase the spot size and coupling efficiency. Claims that fast ignition will ease target fabrication requirements and enable single-sided compression need to be verified through a set of calculations that develop gain curves for fast ignition targets with reduced surface quality.

Target fabrication: In addition to target design activities that will determine acceptable surface roughnesses, techniques for fabrication of fast ignition targets need to be explored. Although we will not perform any experimental work, we will identify key differences in fast ignition targets-including tritium-lean varieties-and identify and quantify advantages and disadvantages relative to traditional central hot spot targets. We will study potential techniques for mass production of fast ignition targets within specifications and at an acceptable cost.

Blanket engineering: If fast ignition is used with tritium-lean targets, the parameter space for blanket design greatly increases. We will explore a set of alternative blanket materials that are selected for characteristics such as vapor pressure, chemical compatibility, power conversion, pumping power, and safety. We will complete a survey of liquids and down-select to approximately six that appear attractive. Upon completion of this survey, we will recommend analysis and experiments that will enable further down-selection. We will consider the possibility of supplemental tritium breeding (TBR < 1 blankets with breeding in the target and/or target casing) and its effects upon safety and economics.

Power plant evaluations: Fast ignition has the potential to revolutionize thinking about IFE power plants. We will integrate the results from the target design, target fabrication, and blanket design tasks into preliminary fast-ignited, power plant designs for one or more of the three target concepts. In the most conservative of these, we will assume traditional D-T targets with a typical breeding blanket and a typical repetition rate but significantly reduced total driver energy. For the intermediate case, we will assume the original driver energy, but we will take advantage of greatly increased yields per target and reduce the repetition rate and pumping power. Finally, in the most aggressive design, we will employ advanced, tritium-lean targets that allow TBR << 1 and lower repetition rates. For each design, we will assess the technical risks, quantify the advantages and disadvantages, and make preliminary estimates of the COE. This study will set the stage for much more detailed power plant studies, which typically cost more than $1M.

Proposed Budget, Schedule, Milestones, and Deliverables

The proposed budget for this project is ~ $340K per year for 3 years. Table 1 identifies the level of effort in each area for each year. Table 2 lists milestones and completion dates for each year (assuming a 10/1/00 start). Annual progress reports will be published as well as a final report. Results and findings will be published in refereed journals.

During the first year, target design work will focus on development of fast ignition gain curves and a survey of the effects of surface roughness upon target performance. Target fabrication specialists will work with the target designers to ensure that candidate targets could be manufactured. Reviews will be conducted for potential blanket materials, and a database of properties will be assembled. Neutronics models will guide the blanket engineering task with assessments of tritium breeding, energy multiplication, and neutron activation. Models will be created to assess the economics of fast ignition power plants.

Table 1. Effort will be split into four main areas at a total average cost of $340K per year.

	Level of Effort (FTE-years)					
Year	Target Design	Target Fabrication	Blanket Engineering	Power Plant Analyses	Total	Cost (K$)
FY01	0.33	0.50	0.50	0.33	1.66	$333
FY02	0.33	0.50	0.50	0.33	1.66	$333
FY03	0.25	0.25	0.25	1.00	1.75	$350

During the second year, the target designs developed during the first year will be optimized for use with the two more conservative power plants designs. Designers will also validate concepts for tritium-lean targets, attempting to maximize charged particle production. Target fabrication activities will focus on the methods of production for these targets. Blanket materials will be down-selected to 2-3 options for each of the three power plant concepts, and additional parametric studies will be performed for each option. Basic safety and environmental assessments will be performed for each power plant design. Economic analyses will incorporate the expected differences in target fabrication facilities for traditional, fast-ignited, and tritium-lean target designs.

In the third year, target design activities will be limited to minor "tweaking" of the existing designs. Target fabrication work will focus on mass production techniques and the recycling of target materials. Blanket engineering will select a baseline case for each of the three designs. Preliminary evaluations for power plant options will be completed, including power conversion system design, safety and environmental analysis, and preliminary economic assessments. All tasks will identify the areas of highest leverage and greatest technical risk. Recommendations will include specific experiments and/or analyses that should be conducted to reduce this risk.

Table 2. List of milestones and schedule.

Year	Task Description	Completion Date
FY01	Integrated calculation for shielded, single-sided compression target	2/1/01
	Gain curve available for shielded, single-sided compression target	5/1/01
	Completion of blanket materials database	5/1/01
	Neutronics evaluations (1-D) of blanket materials	7/1/01
	Guidance provided to target fabrication on ability to tolerate surface roughness	8/1/01
	Cost analysis for 50-500 kJ ignition laser	9/1/01
FY02	Down-selection of candidate blanket materials	2/1/02
	Spot size optimization for shielded, single-sided compression target	4/1/02
	Scoping study for mass production techniques for target fabrication	4/1/02
	Safety and environmental analyses of blanket concepts	4/1/02
	Fast-ignited, tritium-lean target gain curve available	6/1/02
	Economic analysis of target fabrication facilities	9/1/02
FY03	Report on mass production techniques for target fabrication	2/1/03
	Report on recycling methods for target materials	4/1/03
	Safety and environmental evaluations completed for plant concept(s)	4/1/03
	Economic evaluations completed for plant concept(s)	4/1/03
	Evaluation of plant concept(s)	6/1/03
	Summary report released	8/1/03
	Findings and recommendations submitted for publication	9/1/03

References

[1] M. Tabak et al., "Ignition and High Gain with Ultrapowerful Lasers," *Phys. Plasmas* **1** (1994) 1626.
[2] M. Tabak, "What is the Role of Tritium-Poor Fuels in ICF?," *Nucl. Fusion* **36** (1996) 147.
[3] S. Atzeni and M. L. Ciampi, "Burn Performance of Fast-Ignited, Tritium-Poor ICF Fuels," *Nucl. Fusion* **37** (1997) 1665.
[4] J. F. Latkowski et al., "Safety and Environmental Advantages of Using Tritium-Lean Targets for Inertial Fusion Energy," Presented at the First International Conference on Inertial Fusion Sciences and Applications, Bordeaux, France (1999).
[5] R. B. Stephens et al, "The Case for Fast Ignition as an IFE Concept Exploration Program," Proceedings of the 1999 Fusion Summer Study, Snowmass, CO (1999).

Qualifications of Performers

Dr. Jeffery F. Latkowski is a nuclear engineer in the Applied Research Engineering Division at Lawrence Livermore National Laboratory and a recipient of the Director's Performance Award for "exceptional effectiveness in defining and defending the ES&H position of the National Ignition Facility." His research interests include nuclear safety and environmental issues, radiation transport, neutron activation, and power plant design.

Dr. B. Grant Logan is the Deputy Director for Heavy-Ion Fusion at the Virtual Laboratory for Technology for Fusion Energy Science. His specialties include fusion concept exploration, fusion engineering, systems analysis, and technical management of fusion programs. He received the Earnest O. Lawrence Award in 1980 and the Fusion Power Associates Leadership Award in 1999.

Dr. Wayne R. Meier is the IFE Technology Program Leader at Lawrence Livermore National Laboratory. He has over 24 years of experience in all aspects of IFE technology including neutronics, chamber design, systems analysis, power plant design studies, and R&D planning.

Dr. L. John Perkins is a physicist in the Inertial Fusion Energy Program at Lawrence Livermore National Laboratory. He has extensive experimental and analytical experience in both inertial and magnetic fusion. His current research interests include inertial confinement fusion, fusion plasma physics, fusion reactor design, computational modeling and large code development, nuclear physics and nuclear instrumentation, 14MeV neutron sources.

Dr. Per F. Peterson is a Professor in the Department of Nuclear Engineering at the University of California, Berkeley, and chairs the Energy and Resources Group, an interdisciplinary graduate group at the university. His research interests focus on topics in heat and mass transfer, fluid dynamics, and phase change. He is a co-developer of TSUNAMI, the multi-dimensional code currently used to model gas dynamics and mass transfer in inertial confinement fusion reaction chambers like the National Ignition Facility.

Dr. Richard B. Stephens is a Senior Technical Advisor at General Atomics, which he joined in 1986. He has been head of the Characterization and Chemistry group of the Inertial Confinement Fusion Technology Division of the Fusion Group in GA since 1992. In addition to developing analytical techniques, he has developed innovative inertial fusion target concepts, directed target material research programs for shells, and analyzed their optical and thermal properties. Dr. Stephens has over 50 publications and 10 patents.

Dr. Max Tabak is the leader of the ICF Applications Group in X-Division at Lawrence Livermore National Laboratory. He is a Fellow in the Division of Plasma Physics of the American Physical Society and lead inventor of the fast ignition concept. He is the co-inventor of the Starlight inertial fusion energy concept. His current research is focused on the design of inertial fusion capsules driven by lasers or ion beams. He is author or co-author of over 150 reports and publications.